Which Junction Loss Methodology Do We Use?

By:

Roger T. Kilgore, PE
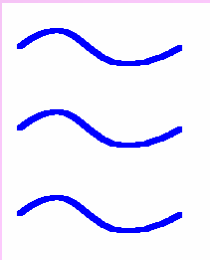
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&

Joe Krolak, PE

Federal Highway Administration
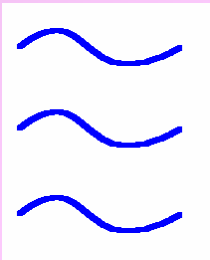
August 8, 2001

U.S. Department of Transportation

Proposed Access Hole Energy Loss Method

By:

Roger T. Kilgore, PE

Kilgore Consulting and Management
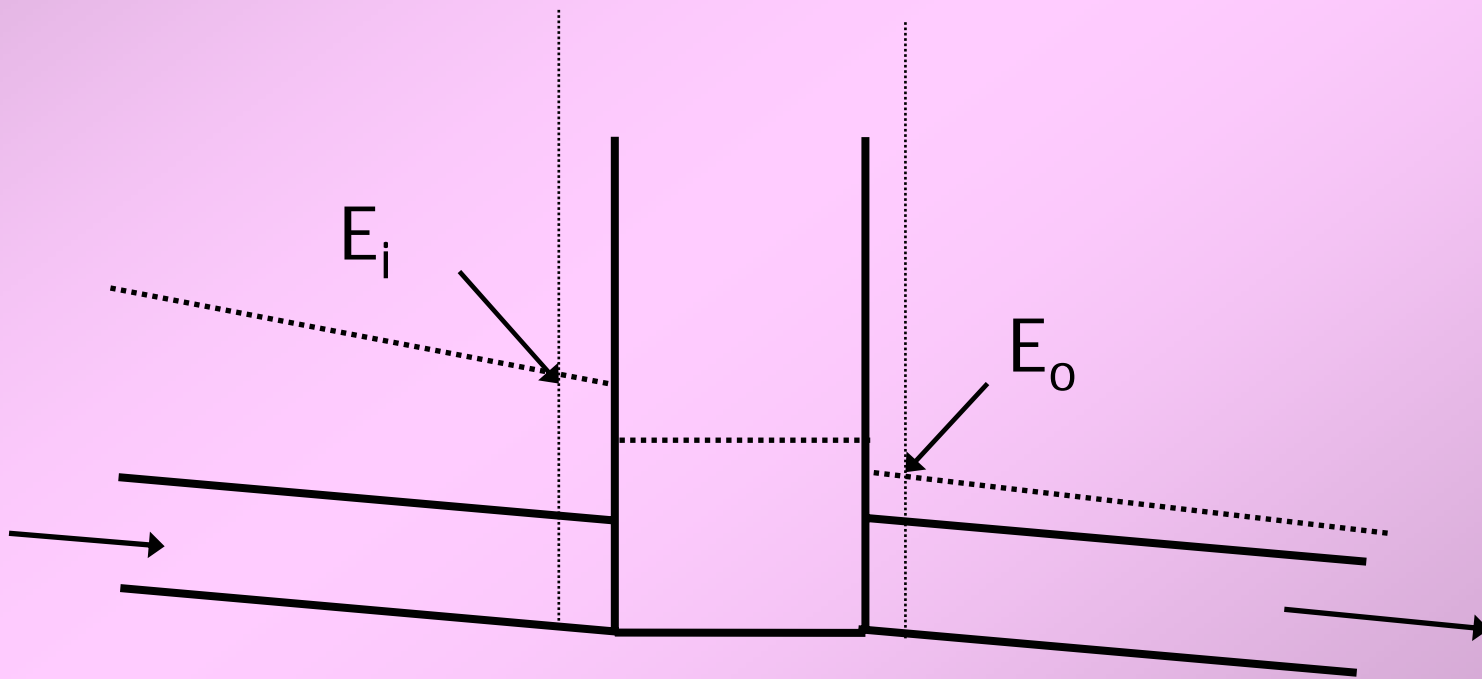
August 26, 2003

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Why do we care?

❖ Although "minor", junction losses can add up.

❖ Simple methods require selection of arbitrary energy loss coefficients.

❖ Complex methods require many variables and may be computationally challenging.

❖ Unreasonable results have been reported with existing methods.

Junction Loss Defined

$$\Delta E = E_i - E_o$$
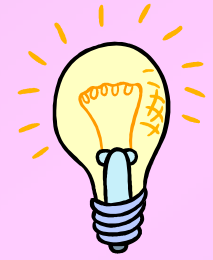
Available Methods

❖ Absolute Method

❖ Standard Method

- HEC-22 approach based on 1989 Lab Report by Chang and Kilgore (HYDRAIN V5.0)

- HYDRA approach based on 1994 Research Report by Chang, Kilgore, Woo, and Mistichelli (HYDRAIN V6.x)

❖ Generic Method

- Power Loss Approach, Chang, et al., 1994

Standard Method

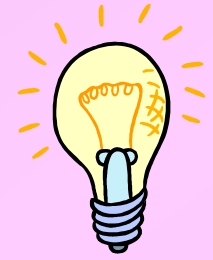$$\Delta E = K \left(\frac{V_o{}^2}{2g} \right)$$

❖ Where does K come from?
- HEC-22 has values ranging from 0.15 to 1.5
- Many situations not represented

FHWA Approaches for K

- Based on laboratory results
- Considered variations in parameters

$$\Delta E = K\left(\frac{V_o{}^2}{2g}\right)$$

HEC-22 Approach

$$K = K_o C_D C_d C_Q C_p C_b$$

Where,

K_o = relative junction size
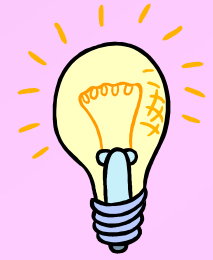
C_D = relative pipe diameter
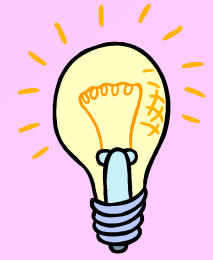
C_d = flow depths

C_Q = lateral inflows

C_p = plunging flow

C_b = benching

Independent Variables for K

- b/D_o
- θ
- D_o/D_i
- y_a/D_o
- Q_i/Q_o
- h/D_o
- (h-y_a)/D_o
- Benching type

- Dimensionless ratios
- Compute a single number, K
- Multiply K by outflow pipe velocity head

HYDRA Approach

$$K = (C_1 C_2 C_3 + C_4) C_b$$

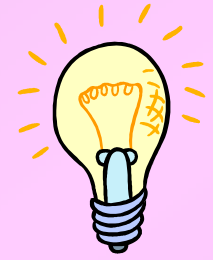Where,

C_1 = relative junction size

C_2 = water depth in manhole
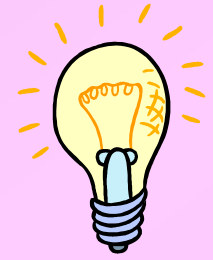
C_3 = lateral inflow, plunging flow

C_4 = relative pipe diameter

C_b = benching

Independent Variables for K

- b/D_o
- θ
- D_o/D_i
- y_a/D_o
- Q_i/Q_o
- h/D_o
- $(h-y_a)/D_o$
- Benching type

- Dimensionless ratios
- Compute a single number, K
- Multiply K by outflow pipe velocity head

Generic Method

$$\Delta E = K_o \left(\frac{V_o^2}{2g} \right) + K_i \left(\frac{V_i^2}{2g} \right)$$

❖ Loss coefficients on the inflow and outflow velocity heads.

❖ Conceptual model of entrance and exit losses.

❖ Where do we get the K_o and K_i values?

Power Loss Approach

$$\Delta E = \alpha_o \left(\frac{V_o^2}{2g} \right) + \sum \alpha_i \left(\frac{V_i^2}{2g} \right) + \sum \text{plunging losses}$$

❖ Power in – Power out = Power Lost

❖ Generic method is a simplification of the Power Loss method.

❖ α_o and α_i are functions of similar parameters discussed earlier.
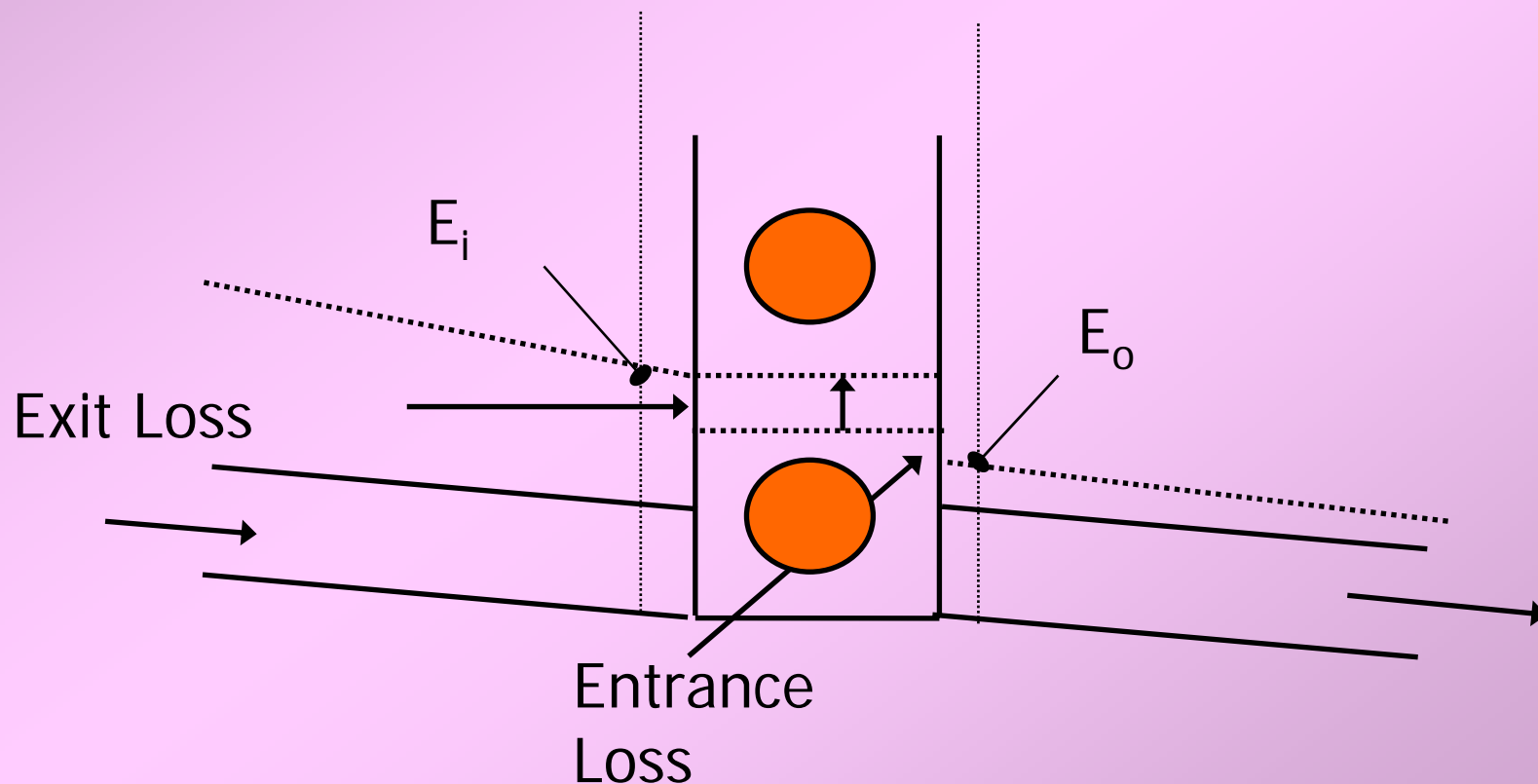
❖ Iterative; closed form.

Issues

❖ Standard Method: Focus on a K factor which is multiplied by an outflow velocity head

❖ Power Loss Method: Iterative solution required

❖ Generic Method: Provides no source for K values

❖ Dependence on Velocity Head

- Inlet control

- Supercritical Flow

- Relationship between lab/computed velocities
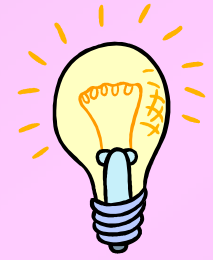
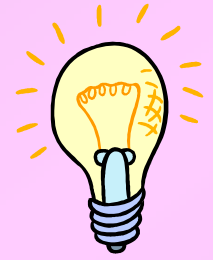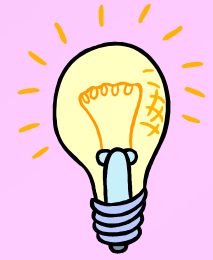# Revisit Definition

$$\Delta E = E_i - E_o$$

Proposed Method

1. Entrance Losses: access hole depth, y_{a1}
2. Additional Losses: benching, angle inflows, and plunging inflows, revised access hole depth, y_a
3. Exit Losses: each inflow pipe
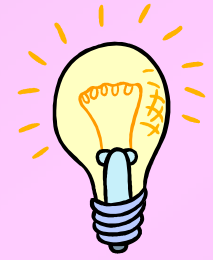
Known: HGL_0 and EGL_o

- ❖ Downstream conditions.
- ❖ Datum: invert of outflow pipe.

1. Entrance Losses

❖ Estimate initial y_{a1}

❖ Adapt concepts of inlet control and full flow for culverts.

Full Flow

❖Full Flow: $HGL_o > D_o$

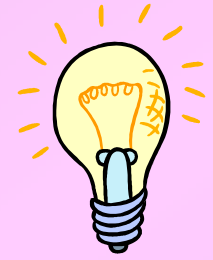$$y_{a,oc} = y_o + P_o + \frac{V_o^2}{2g} + \Delta E_{oc}$$

$$\Delta E_{oc} = K_o \left(\frac{V_o^2}{2g} \right)$$

K_o

$$K_o = 0.2$$

❖ Captures the contraction losses entering the outflow pipe, as in a culvert

❖ Entrance loss coefficients from HDS-5 range from 0.2 to 0.9

❖ b/D_o, relative access hole size, not a factor

Inlet Control

❖ Entrance to outlet pipe controls flow into outlet pipe.

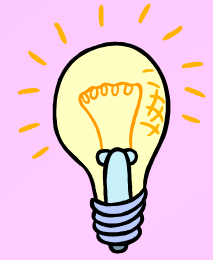❖ Weir or orifice flow: calculate both and take largest headwater

❖ Discharge Intensity:

$$\frac{Q_o}{A_o D_o^{0.5}} \quad \longrightarrow \quad \frac{Q_o}{\sqrt{2g} D_o^{2.5}}$$

Submerged (Orifice)

$$y_{a,ics} = 3.9 \left(\frac{Q}{\sqrt{2g} D_o^{2.5}} \right)^2 D_o$$
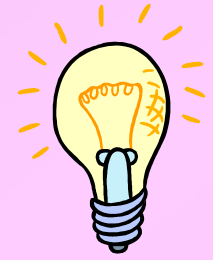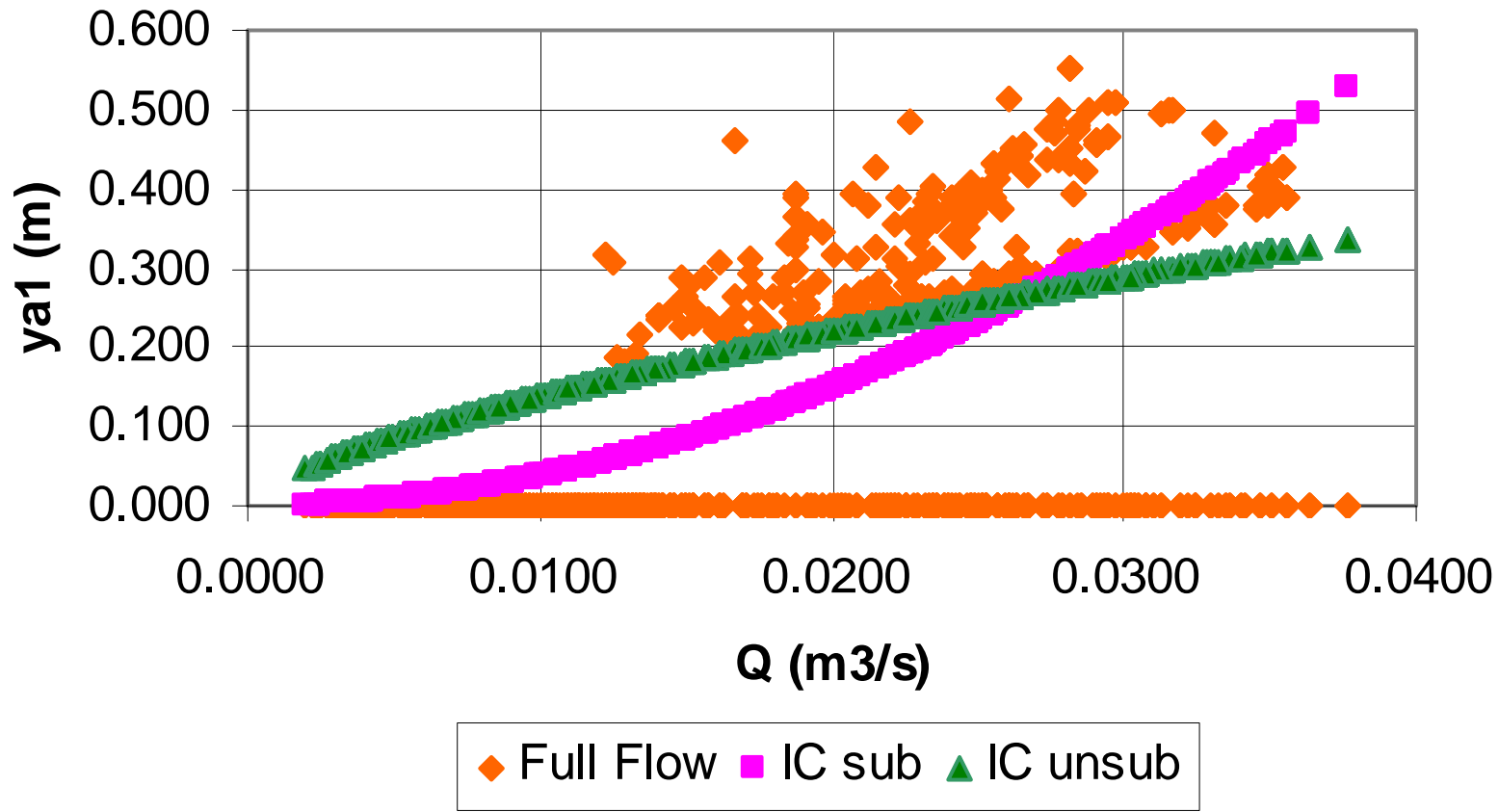
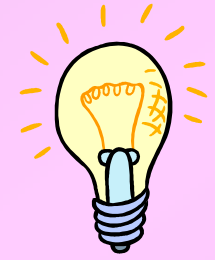❖ 3.9 coefficient is best fit

Unsubmerged (weir)

$$y_{a,icu} = 2.3 \left(\frac{Q}{\sqrt{2g}D_o^{2.5}} \right)^{0.67} D_o$$

❖ 2.3 coefficient is best fit

Initial Depth

2. Additional Losses

- ❖ Benching
- ❖ Angled inflow
- ❖ Plunging inflow

$$y_a = y_{a1} + \Delta E_B + \Delta E_\theta + \Delta E_H$$

Reference Dimension

$$\Delta E = C\left[(y_{a1} + \frac{\alpha Q_o^2}{2gA_a^2}) - \left(y_o + P_o + \frac{Q_0^2}{2gA_o^2}\right)\right] \qquad \alpha = f\left(\frac{by_{a1}}{D_o^2}\right)$$

$$\Delta E = C\left[y_{a1} - \left(y_o + P_o\right)\right]$$

Benching, C$_B$

Floor Configuration	Bench Submerged*	Bench Unsubmerged*
Flat (level)	-0.05	-0.05
Depressed	0.0	0.0
Half Benched	-0.05	-0.65
Full Benched**	-0.25	-0.93
Improved**	-0.60	-0.98

*Submerged: $y_a > 2.5\, D_o$

**Not tested in FHWA data.

Angle Inflows, C_θ

$$C_\theta = 0.5 \left| \cos \frac{\theta_w}{2} \right|$$

$$\theta_w = \frac{\sum Q_i \theta_i}{\sum \theta_i}$$

❖ Include each inflow pipe where $z_i < y_{a1}$

❖ θ is angle with respect to outflow pipe, e.g. θ for straight through = 180°

Plunging Inflows, C_H

$$C_H = 0.35 \sum \left[\left(\frac{Q_i}{Q_o} \right)^{0.75} \left(1 + H_i^{0.3} \right) \right] \qquad H_i = \frac{z_i - y_{a1}}{D_0}$$

❖ Include each inflow pipe where $z_i > y_{a1}$

❖ Includes inlet flow, if present.

3. Exit Losses

❖ If $y_a < z_i$ then there are no exit losses and the EGL is computed using inflow pipe hydraulic parameters

❖ If not, compute exit losses:
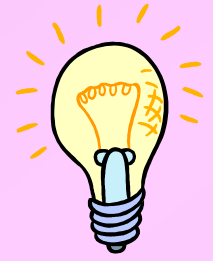
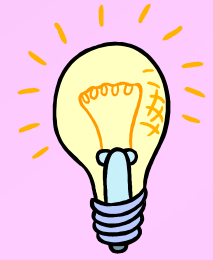$$\Delta E_i = K_i \left(\frac{Q_i^2}{gD_i^4} \right)$$

K_i

$$K_i = 0.46\left(\frac{b}{D_i}\right)^{0.55}$$

- ❖ Captures the expansion losses entering the access hole
- ❖ b/D_i = relative access hole size
- ❖ $1 < b/D_i < 4$
- ❖ Effect of access hole size modest

Calculate HGL_i and EGL_i

❖Calculated for each pipe.

❖Process continues upstream.

FHWA Data Set

- ❖ All Runs
  - 740 configurations/discharges
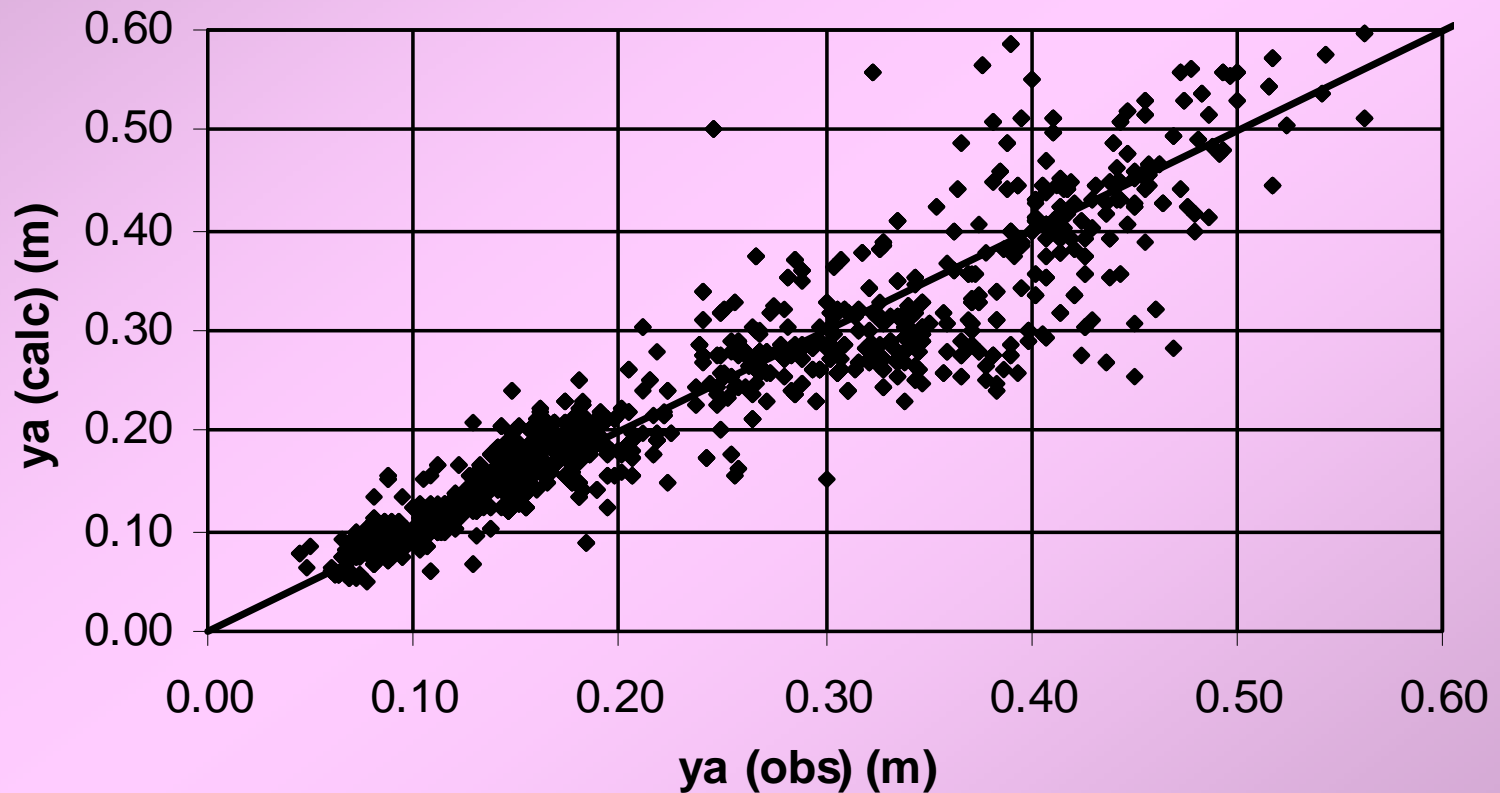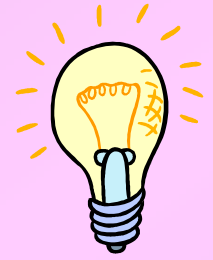 - 1618 inflow pipes
  - 2.2 inflow pipes/run
- ❖ Base Runs
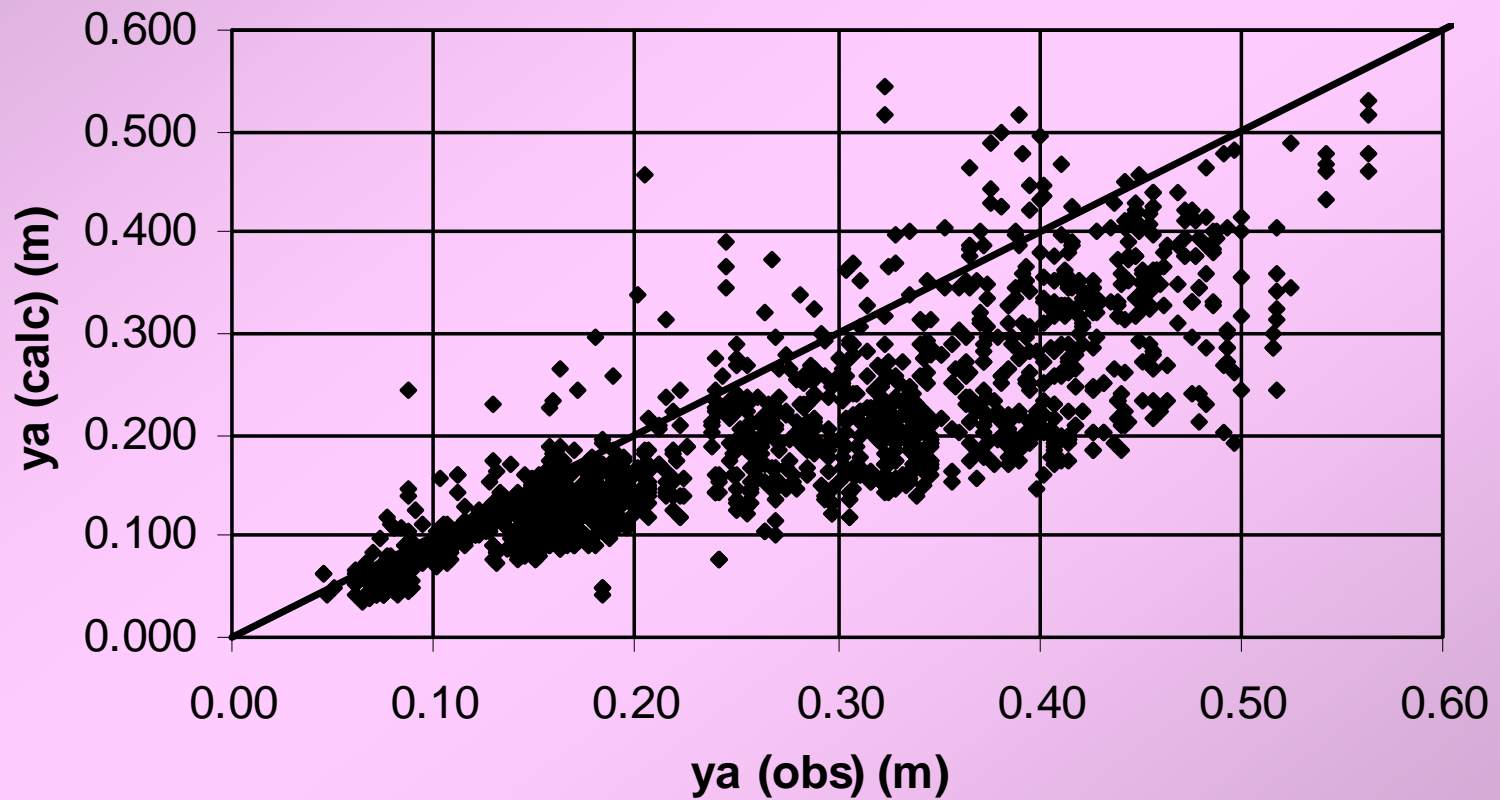 - 1 inflow pipe and equal inverts
  - 68 runs

Performance

❖ Access Hole Depth, y_a
- HEC-22: RMS = 0.094 m
- HYDRAIN: RMS = 0.048 m*
- Proposed: RMS = 0.047 m

❖ Inflow Energy Gradeline, E_i
- HEC-22: RMS = 0.072 m
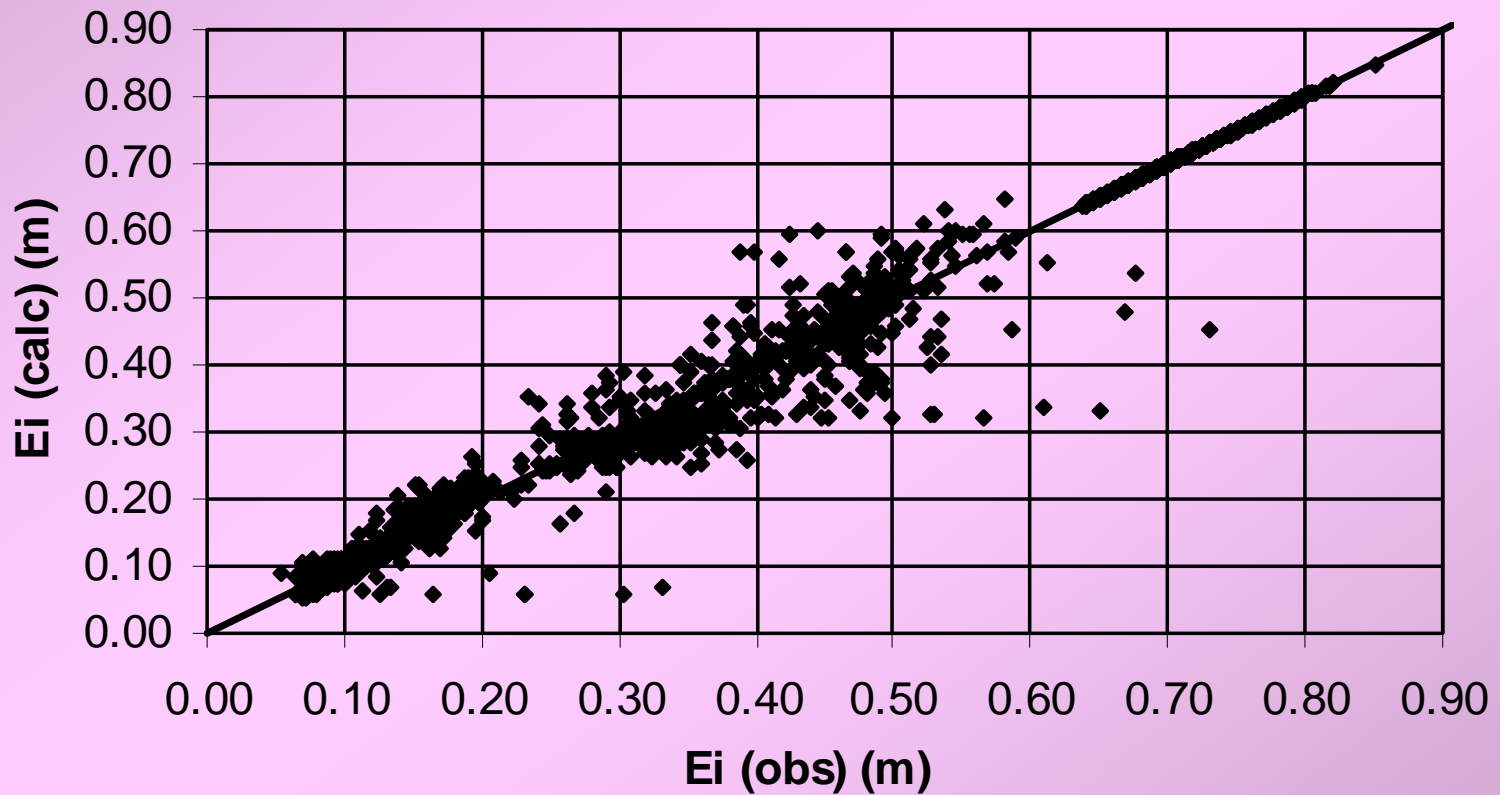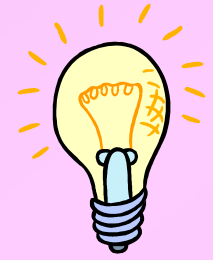- HYDRAIN: not reported.
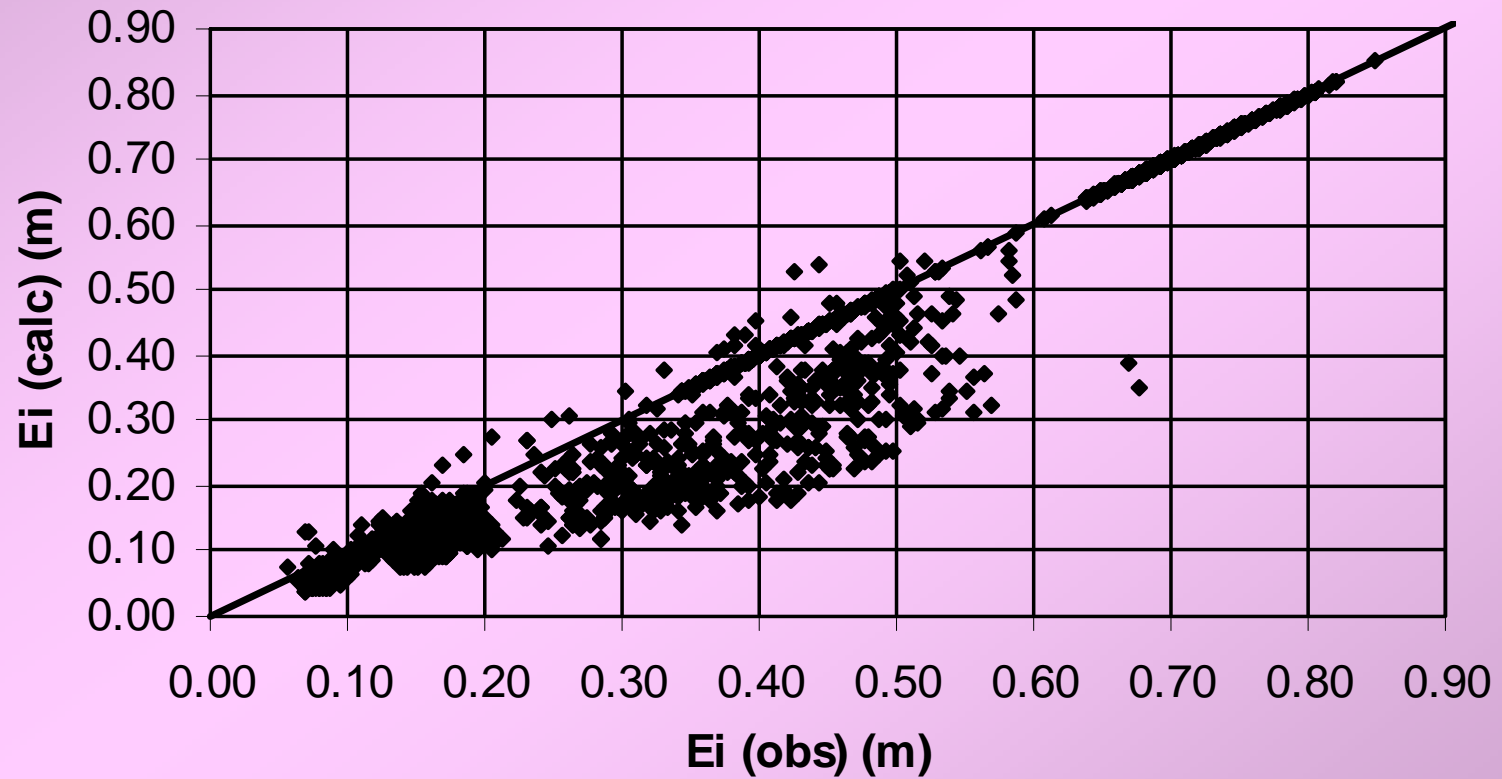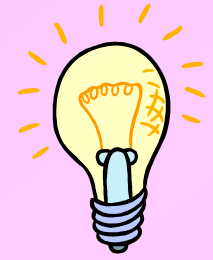- Proposed: RMS = 0.037 m

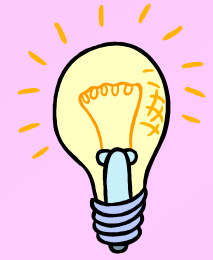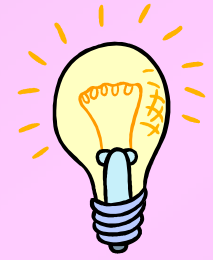# Proposed: y$_a$

HEC-22: y_a

Proposed: E$_i$

HEC-22: E$_i$

Reasons for Adoption

1. Hydraulically sound fundamentals
2. Move away from velocity head for supercritical and inlet control flows
3. Direct, non-iterative procedure
4. Simpler format
5. Equivalent or better RMS

Next Steps

❖ Perform selected additional laboratory experiments

❖ Refine method